Recent trends in the abundance of the invasive green crab (*Carcinus maenas*) in Bras d'Or Lakes and Eastern Nova Scotia based on trap surveys

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RECENT TRENDS IN THE ABUNDANCE OF THE INVASIVE GREEN CRAB (*CARCINUS MAENAS*) IN BRAS D'OR LAKES AND EASTERN NOVA SCOTIA BASED ON TRAP SURVEYS

by

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ABSTRACT

Tremblay M.J., A. Thompson and K. Paul. 2006. Recent trends in the abundance of the invasive green crab (*Carcinus maenas*) in Bras d'Or Lakes and Eastern Nova Scotia based on trap surveys Can. Tech. Rep. Fish. Aquat. Sci. 2673: iii + 32 p.

Trapping surveys for the invasive green crab (*Carcinus maenas*) were undertaken in Eastern Nova Scotia and in the Bras d'Or Lakes in 1999-2000 and 2005. Interviews were also conducted with fishermen and other coastal inhabitants. Green crab were widespread throughout the sampling area and showed no change in range over the time period. Green crab abundance either decreased or did not change between 1999-2000 and 2005. Catch rates of green crab in the Bras d'Or Lakes were lower in 2005 than the earlier period. The decline in green crab abundance in Bras d'Or Lakes was not clearly linked to lower water temperatures. Outside of the Bras d'Or Lakes, there were no significant differences in green crab catch rate between 1999-2000 and 2005.

RÉSUMÉ

Tremblay M.J., A. Thompson and K. Paul. 2006. Recent trends in the abundance of the invasive green crab (*Carcinus maenas*) in Bras d'Or Lakes and Eastern Nova Scotia based on trap surveys Can. Tech. Rep. Fish. Aquat. Sci. 2673: iii + 32 p.

Nous avons effectué des relevés au casier du crabe vert (*Carcinus maenas*), une espèce envahissante, dans l'est de la Nouvelle-Écosse et le lac Bras d'Or en 1999-2000 et 2005. Nous avons également interrogé des pêcheurs et d'autres habitants de ces régions côtières. Le crabe vert était répandu à l'échelon de la zone échantillonnée et n'a montré aucun changement dans son aire de répartition durant cette période, alors que son abondance a soit diminué ou est demeurée au même niveau. Les taux de capture de cet envahisseur dans le lac Bras d'Or étaient plus faibles en 2005 qu'en 1999-2000. Le déclin apparent de son abondance dans le lac Bras d'Or n'était pas relié à une température plus basse de l'eau. Aucune différence significative dans les taux de capture à l'extérieur du lac Bras d'Or entre 1999-2000 et 2005 n'a été relevée.

INTRODUCTION

The invasive green crab (*Carcinus maenas*) was first observed in Atlantic Canada in the outer Bay of Fundy in the early 1950s (MacPhail 1953). By 1954 green crab had reached southwest Nova Scotia (Wedgeport) and by the mid-1960s, St. Margaret's Bay (Audet et al. 2003). Green crab were not reported in eastern Nova Scotia (the Atlantic coast of Nova Scotia east of Halifax) until the early 1980s and were reported in Chedabucto Bay by 1991. The timing of their entry to the Bras d'Or Lakes is uncertain, but they likely arrived in the early 1990's. On the Atlantic shore of Cape Breton, they were as far north as Ingonish at least as early as 1997. Green crab were first detected in western Cape Breton (southern Gulf of St. Lawrence) in 1994 (Audet et al. 2003). The green crab that have reached new areas in the last 10-15 years may have originated from populations on the eastern shore, but there is some evidence that they arrived from separate introduction events (Cameron and Metaxas 2005).

Green crab are well known predators of bivalves (MacPhail 1953, Elner 1981, Miron et al. 2005), and can negatively affect bivalve fisheries (Walton et al. 2002, Congleton et al. 2005). With apparent increased abundance of green crab in eastern Nova Scotia, there was concern about their effect on clam harvests on the eastern shore, and on oysters in the Bras d'Or Lakes. There is also evidence that green crab can compete effectively with lobster and rock crab in some situations (Miron et al. 2005, Williams et al. 2006, Rossong et al. 2006).

There was (and is not currently) any monitoring system in place for green crab or other invasive crabs in Nova Scotia. To address this deficiency, sampling by traps was conducted in Bras d'Or Lakes and selected locations on the eastern shore and in eastern Cape Breton in 1999-2000 (Tremblay 2002). A standard sampling protocol was developed, and the catch rate in traps was assumed to be an index of abundance. In 2003 and 2004, there was anecdotal information about declines in green crab in some areas. In the present study we evaluate recent trends in green crab abundance by comparing the results from a 2005 trapping survey with that done in 1999-2000. The area of focus was Cape Breton to Halifax County, with a special emphasis on the Bras d'Or Lakes (Fig. 1, 2).

METHODS

TRAP SURVEYS

Sampling for green crab was conducted in Eastern Nova Scotia and the Bras d'Or Lakes primarily in summer during two periods: 1999-2000 and 2005 (Tables 1 and 2). Site selection was haphazard, based on local knowledge and ease of access for sampling. Many sites were adjacent to public wharves and only a few headlands were sampled. Sites ranged from 1-20 km apart, with site density higher in the Bras d'Or Lakes because of a special concern about the impact of green crab in this area. Many of the sites sampled in 1999-2000 were again sampled in 2005.

Samples were obtained by setting three traps, each baited with about 250 gm of mackerel or herring. The wire mesh traps were cylindrical in shape with a length of 91.4

cm, a diameter of 30.5 cm and mesh openings of 2.5 cm by 1.3 cm (Fig. 3). At each site the three traps were distributed over a range of depths, to a maximum depth of 4.6 m (15'). Average depths for traps over all sites were: 1.4 m (shallowest trap), 1.8 m (intermediate depth trap) and 2.3 m (deepest trap). Set times were approximately 3 hours at each site (mean = 3.3 h [1999], 3.1 h [2000] and 3.0 h [2005]). Typically 3-5 sites were sampled per day, all during daylight. A sample consisted of the contents from the three trap hauls at one site. For each site the substrate, trap depth and soak time were recorded. Latitude and longitude was determined with a hand held Global Positioning System (GPS).

The contents from each trap haul were processed as follows. Crab were measured to the nearest mm (carapace width or CW), sexed, and checked for eggs. In 1999-2000 other taxa were identified but not recorded consistently; in 2005 all taxa were recorded and rock crab were measured in the same manner as green crab. Digital photographs were taken of the catch at most 2005 sites. The total catch was released back to the water after processing.

TRAP DATA ANALYSIS

The total number of green crab per sample was modeled as a function of year and area in analysis of variance (anova). Two data sets were examined:

1. Eastern Nova Scotia Counties – those counties with at least 3 samples in 1999-2000 and 3 samples in 2005. The 3 counties were Victoria, Richmond and Guysborough.

2. Bras d'Or Lakes. Those subareas within the Bras d'Or Lakes with at least 3 samples in 1999-2000 and 3 samples in 2005. These subareas were Bras d'Or Lake central, Denys Basin, East Bay, West Bay, St. Peters, St. Andrews Channel, St. Patrick's Channel and Great Bras d'Or Channel. The subareas that were excluded with this criteria were Cape Dauphin, North Basin and Wycocomagh Bay.

The analyses and most graphics were done using R, an open source statistical and graphical language and environment.

INTERVIEWS

Local knowledge on the timing of green crab arrival, on recent population trends and on the perception of local impact, was gathered by interviews conducted in 2000 and 2005 (Table 3, Appendix 1). The interviews were conducted primarily in areas adjacent to sampling locations and to areas of high fishing or aquaculture activity. Interviews were conducted in coastal areas of the counties of Halifax, Guysborough, Richmond, Cape Breton and Victoria Counties, and around Bras d'Or Lakes.

Interviewees were selected by opportunity while sampling, from a list of names generated from DFO license holder lists (e.g. eel and lobster), or by recommendations from other interviewees. The interview consisted of thirteen questions (Appendix 1) and most interviews were conducted in person.

RESULTS

TRAP SURVEYS

A total of 222 samples (one for each date and location) were obtained: 128 in 1999-2000 and 94 in 2005. Sampling was from August to November (Fig. 4, Table 1). In Bras d'Or Lakes, where most samples were obtained, there was a higher proportion of August samples in 1999 compared to 2005.

The total number of green crab captured in the 222 samples was 4565. Most green crab caught were male (73%); of the 27% that were females only 5% had eggs (Fig. 5). Green crab ranged in size from 16-91 mm CW; females were smaller than males. The few ovigerous females were all between 40 and 60 mm CW. Example images of the trap catch are shown in Fig. 6. The catch was comprised primarily of green crab but there were other animals caught (see Bycatch).

The geographic distribution of samples was broader in 2005 than in 1999-2000, but there were more samples in Bras d'Or Lakes in 1999-2000 (Figs. 7, 8). The highest catch rate of green crab (188 in 3 traps) was recorded in 2005 in Cape Breton county at Gabarus (largest circle in Fig. 8), a site not sampled in 1999-2000.

Boxplots of the total number of green crab per sample indicate a decline in catch rates from 1999/2000 to 2005 in Bras d'Or Lakes as a whole (Fig. 9). The green crab catch rate in Victoria and Cape Breton counties suggests a decline, while for other counties there was a possible increase or no change (Fig. 9). Numbers of the smallest green crab (< 30 mm CW) were low and showed no consistent trend (Fig. 10). Within Bras d'Or Lakes, most subareas showed a decline in the total number of green crab from 1999-2000 to 2005 (Fig. 11). Boxplots of the smallest green crab within Bras d'Or Lakes subareas showed no consistent trend over time (Fig. 12).

TRAP SURVEY DATA ANALYSIS

The count frequency for the full data set indicated that the data were not normally distributed (Fig. 13). With samples with zero counts removed, the data were closer to normal after log transformation ($\log_e$). For subsequent analyses of variance the data were log transformed and samples with zero counts were removed. The anova for the Eastern NS county data set indicated no significant effects due to year or location (Table 4). Plots of residuals indicated that the variance was stabilized and there were no serious deviations from normality (Appendix 2). For the Bras d'Or Lakes data set, both year and location (subarea) were significant in the anova (Table 5). 2005 counts were significantly lower than 1999-2000. St. Peters Inlet and West Bay had higher counts than the other subareas, and Denys Basin and St. Andrews Channel had the lowest counts of green crab (Appendix 2).

The high proportion of August samples in 1999 compared to 2005 raised questions about the effect of sample timing on the measured catch rates. For this reason an additional analysis was run with only the September and October samples included (n=37 for 1999 and n=40 for 2005). Total number was modelled as a function of year, subarea and month. Again year and location were significant (Table 6).

With regards to smaller, younger green crab, no significant effects of year or area were detected for either the Eastern NS county data set (Table 7) or the Bras d'Or Lakes data set (Table 8). For this analysis a large proportion of samples were removed prior to analysis because they has zero counts of small crab.

BYCATCH IN TRAPS

Some 16 taxa were captured as a bycatch in the trap samples (Table 9). Cunner were by far the most frequent bycatch. In order of numbers trapped, the next four bycatch taxa were mummichog, rock crab and starfish.

INTERVIEWS

Compared to the interview survey in 2000, there were more interviews in 2005 and they covered a larger geographic area (Table 3). Most of those interviewed were harvesters of lobster or crabs, oysters or clams, or eels (Fig. 14). Observations of green crab were mainly in the intertidal, at maximum depths of less than 5 m (Fig. 15), and in protected areas (Fig. 16). Most interviewees encountered green crab in traps or moving freely on the shore (Fig. 17). Most interviewees indicated they had first seen green crab in their area from 1996-2000 (Halifax, Guysborough, Richmond and Victoria Counties), or 1991-1995 (Cape Breton and Bras d'Or Lakes) (Fig. 18).

In response to the question "In your opinion are there more now then when you first saw it" most interviewees in 2000 in Guysborough and Richmond counties responded "yes", but in 2005, most respondents in all counties responded "no" (Fig. 19). This indicates there was a perception that green crab had declined since 2000. As to when green crab were most numerous, the interviewees usually selected the period 1996-2000 (Guysborough county in 2000 and 2005, Richmond county in 2000, and Victoria county) or 2001-2005 (Halifax county, Richmond county in 2005, Cape Breton county and Bras d'Or Lakes) (Fig. 20).

In most counties interviewees reported seeing a wide size of green crab with most being 76-100 mm CW. Most noted no recent change in green crab size or were unsure (Fig. 21). The exception was Guysborough County in 2000 where about 60% of interviewees thought green crab were larger in recent years.

In response to questions about females with eggs, 55-90% of respondents within counties had not seen any and those that reported seeing them did not recall what season. As for molted green crab, respondents in most counties did not report any. The exception was Victoria county where about 60% of respondents reported seeing molted green crab, mainly in the fall and summer.

DISCUSSION

In both 1999-2000 and 2005 green crab were trapped throughout eastern Nova Scotia, including Bras d'Or Lakes. Their ubiquity and numbers per sample indicate they are firmly established. Below we discuss the utility of green crab catch rate as an index of abundance and the trends in Bras d'Or Lakes and the rest of eastern Nova Scotia.

TRAP CATCH RATE AS AN INDEX OF ABUNDANCE

Catch rates in traps are a function of abundance and the catchability of the target animal. Catchability is affected by trap design, environmental conditions and biological factors. Important environmental conditions for crustaceans are temperature and bottom type; important biological factors are the molting cycle, the reproductive cycle, presence of other food sources and the presence of predators (Miller 1990, Tremblay and Smith 2001). In the current study catchability likely differed between sexes (males higher than females) and possibly between ovigerous and non-ovigerous females. However it is possible that the females and ovigerous females were not in the same locations as the males.

In the current study trap type and soak time were well controlled, as was the within year timing of trapping. We did not control for time of day or tidal cycle, which may have contributed to some variability in catch rates, but not to variation among years or groups of sites. For both sampling periods (1999-2000 and 2005) and for any given area or subarea, sampling was done throughout the day. Tidal cycle was not an issue in Bras d'Or Lakes in any case given the very small tidal amplitude there (Petrie and Bugden 2002).

Annual differences in temperature, and weather could not be controlled for. Given that the trapping took place over several months in each year, and that there were no obvious differences in environmental conditions across years, we think the catch rate of green crab measured in the current study can be used as a coarse indicator of abundance.

TRENDS IN GREEN CRAB IN BRAS D'OR LAKES

Based on the interviews and the timing of first sightings in Audet et al. (2003) it appears green crab appeared in Bras d'Or Lakes sometime in the late 1980s or early 1990s. While they have become relatively abundant in the 15 years from 1990 to 2005, green crab have not undergone a steady increase in abundance over the period. The lower catch rate of green crab in traps in the Bras d'Or Lakes in 2005 compared to 1999-2000 is indicative of reduced abundance. Reduced abundance in Bras d'Or Lakes agrees with a report of lower green crab abundance in western Nova Scotia estuaries in 2003 and 2004 in Rossong et al. 2006.

Similar decreases in catch rates (and by inference abundance) were noted within 10 years of the green crab arrival in the outer Bay of Fundy. Medcof (1958) reported that green crab catch rates dropped from over 300 per trap in 1954 to 65 per trap in 1957. He hypothesized that the decline was related to increased predation by local fauna but could present no firm evidence. Berrill (1982) reported In the Gulf of Maine green crab increased during periodic warm years, and decreased and became uncommon north of central Maine in colder years.

To evaluate the possible role of temperature in the apparent decline in green crab abundance in the Bras d'Or Lakes, DFO's Coastal Time Series database was accessed (Gregory 2004). Available temperature data have some substantial gaps and do not provide strong support for temperature as the factor causing the apparent decline in green crab abundance in Bras d'Or Lakes (Fig. 22). Recent mean temperatures in the upper 5 m for February and March temperatures appear lower than in 1995 and 1996,

while recent means for June-Sept appear higher than 1994-95. Lower temperatures during winter likely are limiting to green crab, but it is not clear yet whether recent temperatures in Bras d'Or Lakes are on the low side for the period since green crab arrived.

TRENDS IN GREEN CRAB OUTSIDE OF BRAS D'OR LAKES

The trapping did not detect a significant change in the abundance of green crab outside of the Bras d'Or Lakes. This is in spite of the interviews in 2005 in Guysborough and Richmond Counties that indicate a perception that 2005 green crab abundance was lower than when first seen, whereas in 2000 the interviews indicated green crab abundance in 2000 was higher then when first seen. Whether this discordance between trapping results and interviews is the result of different interviewees in 2000 and 2005 (with different perceptions), or whether the trapping method was not sensitive enough to detect change is not known.

IMPACTS AND FUTURE APPROACHES FOR DEALING WITH GREEN CRAB

Green crab appear to be firmly established in eastern Nova Scotia. Their abundance may decline in periods of colder temperatures but there is no expectation that they will be extirpated. A number of papers have demonstrated that green crab have the potential to have a negative effect on local biota (Miron et al. 2005, Williams et al. 2006). Eradication attempts are unlikely to be successful particularly using traps such as those in the present study which result in a male-biased catch. At the time of writing there is a proposed experimental fishery for green crab that may help to keep green crab in check. Activities affected by green crab, such as shellfish aquaculture and clam harvesting, will likely need to continue to develop and use practices to reduce any impacts, rather than attempt the eradication of green crab.

Any future monitoring programs for green crab should be more comprehensive and include more of the epibenthic community. The green crab traps used here did sample some of the epibenthic community, but other gear types would be needed to obtain a more representative sample. A well-designed monitoring program could use traps and other gear types to evaluate changes in community structure due to green crab or other biological or physical stresses, and could also provide early warning of new invasives.

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Table 1. Geographic and temporal distribution of 222 trap samples for green crab by County and for Bras d'Or Lakes. Each sample consists of the combined catch of 3 traps set for approximately 3 hours.

Years	Month	Victoria	Cape Breton	Richmond	Anti-gonish	Guys-borough	Halifax	Bras d'Or Total	All areas
1999	Aug	2						34	36
	Sep		1	1				18	20
	Oct							19	19
	Nov	2						15	17
	Total	4	1	1	0	0	0	86	92
2000	Jul		2					6	8
	Aug			4		12		9	25
	Sep			2			1		3
	Total	0	2	6	0	12	1	15	36
2005	Aug	2	2	10	0	12		3	29
	Sep		4	1	2		11	16	34
	Oct							24	24
	Nov	2						5	7
	Total	4	6	11	2	12	11	48	94
Total All Yrs		8	9	18	2	24	12	149	222

Table 2. Geographic and temporal distribution of 149 trap samples for green crab by subarea within the Bras d'Or Lakes. Each sample consists of the combined catch of 3 traps set for approximately 3 hours.

Years	Month	BDL-Central	Denys Basin	East Bay	St Pet	West Bay	CDau-phin	GB Channel	North Basin	Why-Bay	SAnd Chan	SPat Chan
1999	Aug	4	14	4	4	8						
	Sep	1		6	11							
	Oct							5	1			13
	Nov						1	4	4	6		
2000	Jul								1		6	
	Aug				1						7	
	Sep											
2005	Aug				3							
	Sep		4	4		3				2	3	
	Oct	3	3	1	6	3			2		2	4
	Nov							4				1
Total		8	21	15	25	14	1	13	8	8	18	18

Table 3. Distribution of interviews by county and around the Bras d'Or Lakes in 2000 and 2005.

	2000			2005		
County/Area	In person	Phone	Total	In person	Phone	Total
Halilfax	0		0	20	3	23
Guysborough	7	13	20	12	5	17
Richmond	3	11	14	15	0	15
Cape Breton	0		0	6	1	7
Victoria	0		0	8	0	8
Bras d'Or	0	1	1	13	4	17
Grand Total	10	25	35	74	13	87

Table 4. Analysis of variance for effect of Year (1999-2000 combined vs 2005) and Region (Guysborough County and Richmond County and Victoria County) on total number of green crab per sample. Number of samples included in analysis was 45; 6 samples from above 3 counties were removed before analysis because of zero counts.

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```
Analysis of Variance Table
Response: log(Totnoall)
             Df Sum Sq Mean Sq F value Pr(>F)
Year          1  0.027   0.027  0.0149 0.9035
Region        2  1.905   0.952  0.5193 0.5988
Residuals    41 75.183   1.834
```

Table 5. Analysis of variance for effect of Year (1999-2000 combined vs 2005) and subarea within Bras d'Or Lakes (see Table 2) on total number of green crab per sample. Subareas of Cape Dauphin, St. Andrews Channel and Whycocomagh Bay were excluded because of low number of samples. Number of samples included in analysis was 119; 13 samples from included subareas were removed before analysis because of zero counts.

```
Analysis of Variance Table
Response: log(Totnoall)
              Df  Sum Sq Mean Sq F value    Pr(>F)
Year           1  18.165  18.165 18.1866 4.252e-05 ***
Subarea        7  33.167   4.738  4.7436 0.0001097 ***
Residuals    110 109.871   0.999
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 6. Evaluation of the effect of the high proportion of August samples in 1999 compared to 2005 on the interpretation of changes in green crab catch rate. For the anova below, August samples were removed and only samples from September and October were included. Same subareas as in Table 5; samples with zero counts removed before analysis.

```
Analysis of Variance Table
Response: log(Totnoall)
             Df Sum Sq Mean Sq F value    Pr(>F)
Year          1 15.678  15.678 20.4906 3.426e-05 ***
Subarea       7 25.498   3.643  4.7606 0.0003322 ***
Month         1  1.994   1.994  2.6056 0.1124255
Residuals    53 40.553   0.765
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 7. Analysis of variance for effect of Year (1999-2000 combined vs 2005) and Region (Guysborough County and Richmond County) on number of green crab < 30 mm CW per sample. Victoria County excluded because no small green crab were captured in samples. Number of samples included in analysis was 14; 37 samples were removed before analysis because of zero counts.

```
Analysis of Variance Table
Response: log(Nolt30)
             Df Sum Sq Mean Sq F value Pr(>F)
Year          1 0.5094  0.5094  1.1047 0.3158
Region        1 0.5251  0.5251  1.1386 0.3088
Residuals    11 5.0726  0.4611
```

Table 8. Analysis of variance for effect of Year (1999-2000 combined vs 2005) and subarea within Bras d'Or Lakes (see Table 2) on number of green crab < 30 mm CW per sample. Subareas of Cape Dauphin, St. Andrews Channel and Whycocomagh Bay excluded because of low number of samples; St. Patrick's Channel and East Bay excluded because in some years there were no small green crab captured in samples in these locations. Number of samples included in analysis was 18; 114 samples were removed before analysis because of zero counts.

```
Analysis of Variance Table
Response: log(Nolt30)
             Df  Sum Sq Mean Sq F value Pr(>F)
Year          1  3.6537  3.6537  2.9152 0.1158
Subarea       5  6.9085  1.3817  1.1024 0.4124
Residuals    11 13.7866  1.2533
```

Table 9. List of taxa caught as bycatch in green crab traps in descending order of abundance. Guys=Guysborough

	Bras d'Or	----------County----------					
Taxon	Lakes	Halifax	Guys	Richmond	Antigonish	Victoria	Total
Cunner	192	82	336	165	11	0	915
Mummichog	242	0	0	0	1	0	243
Rock Crab	50	0	0	35	0	36	121
Starfish	41	3	0	4	0	2	50
Cod	29	0	0	0	0	1	30
Eel	4	0	6	3	0	1	15
Periwinkles	13	0	0	0	0	0	13
Flounder	10	1	0	0	0	0	11
Capelin	5	0	0	0	0	0	5
Smelt	3	0	0	1	0	0	4
Minnow	4	0	0	0	0	0	4
Hake	0	0	0	2	0	0	2
Sculpin	0	1	0	1	0	0	2
Pollock	0	0	2	0	0	0	2
Brook trout	1	0	0	0	0	0	1
Jellyfish	1	0	0	0	0	0	1

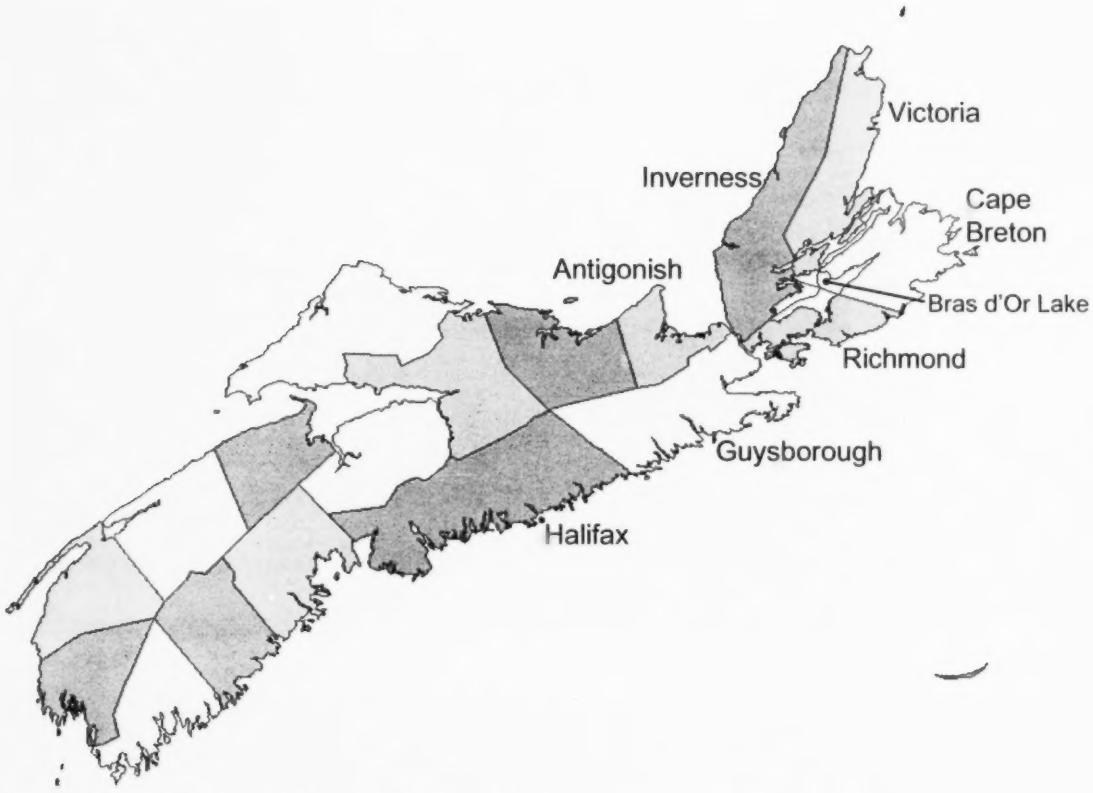


Fig. 1. Map of Nova Scotia showing counties where green crab were sampled, and location of Bras d'Or Lake.

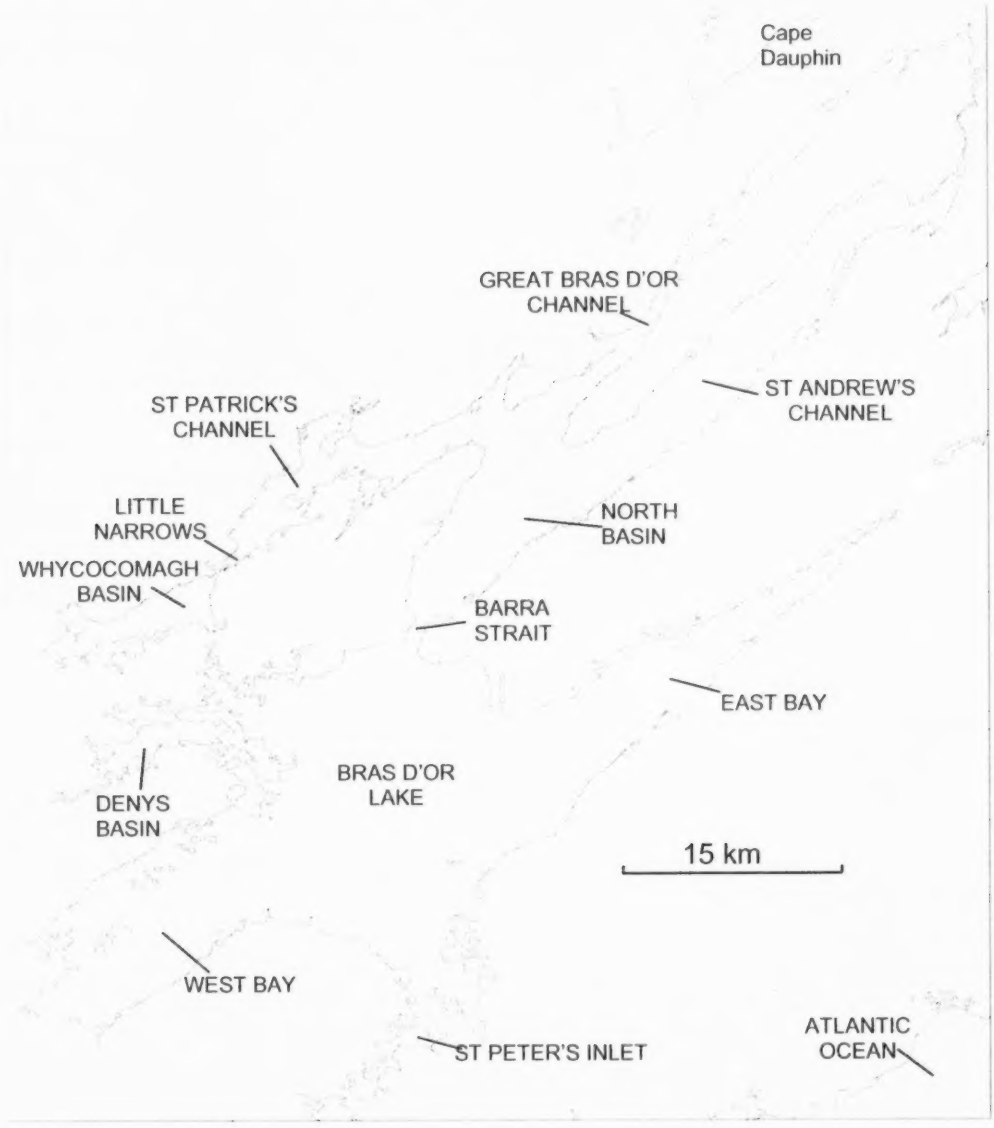


Fig. 2. Map of Bras d'Or Lakes ("Bras d'Or Lakes" includes Bras d'Or Lake and the channels and basins from Barra Strait to the outer coast).

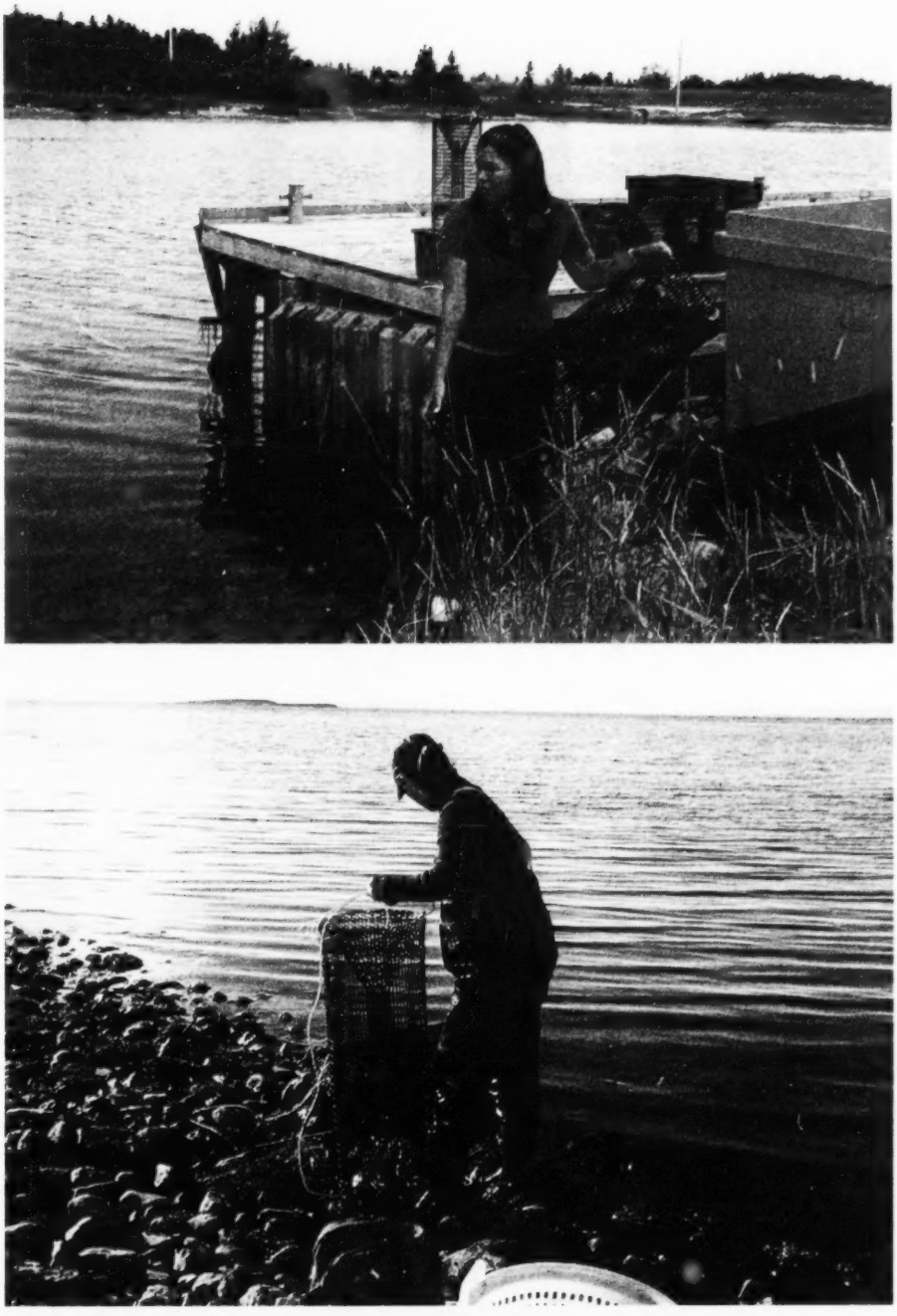


Fig. 3. Deployment of traps for green crab in (a) Dingwall, Victoria County and (b) Bras d'Or Lake.

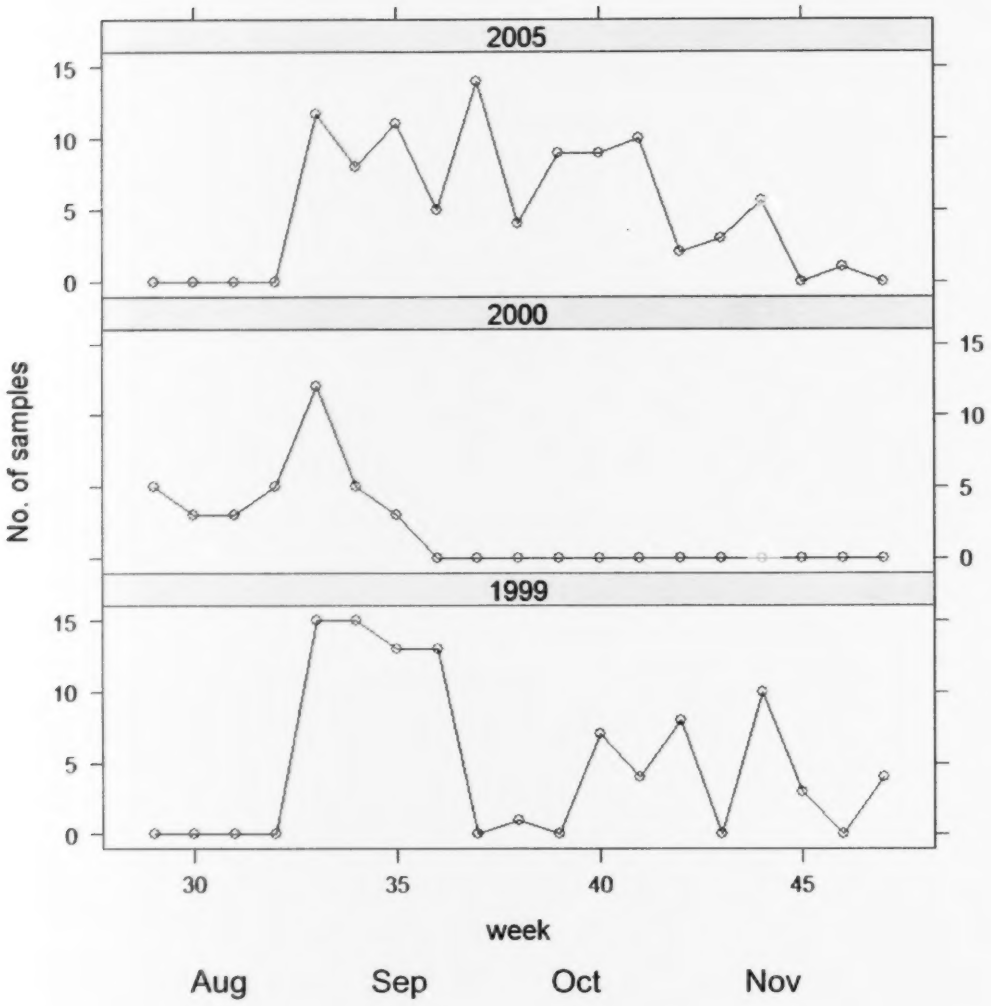


Fig. 4. Temporal distribution of samples in 1999, 2000 and 2005.

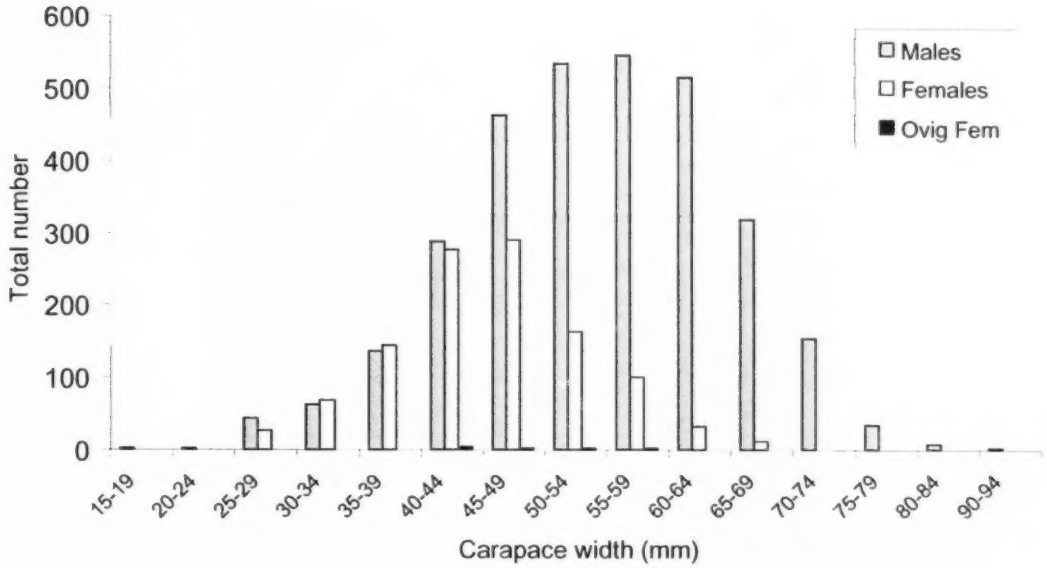


Fig. 5. Size frequency of all green crab measured in traps hauled in 1999, 2000 and 2005. Tot number measured = 4222 (93% of all crab captured).

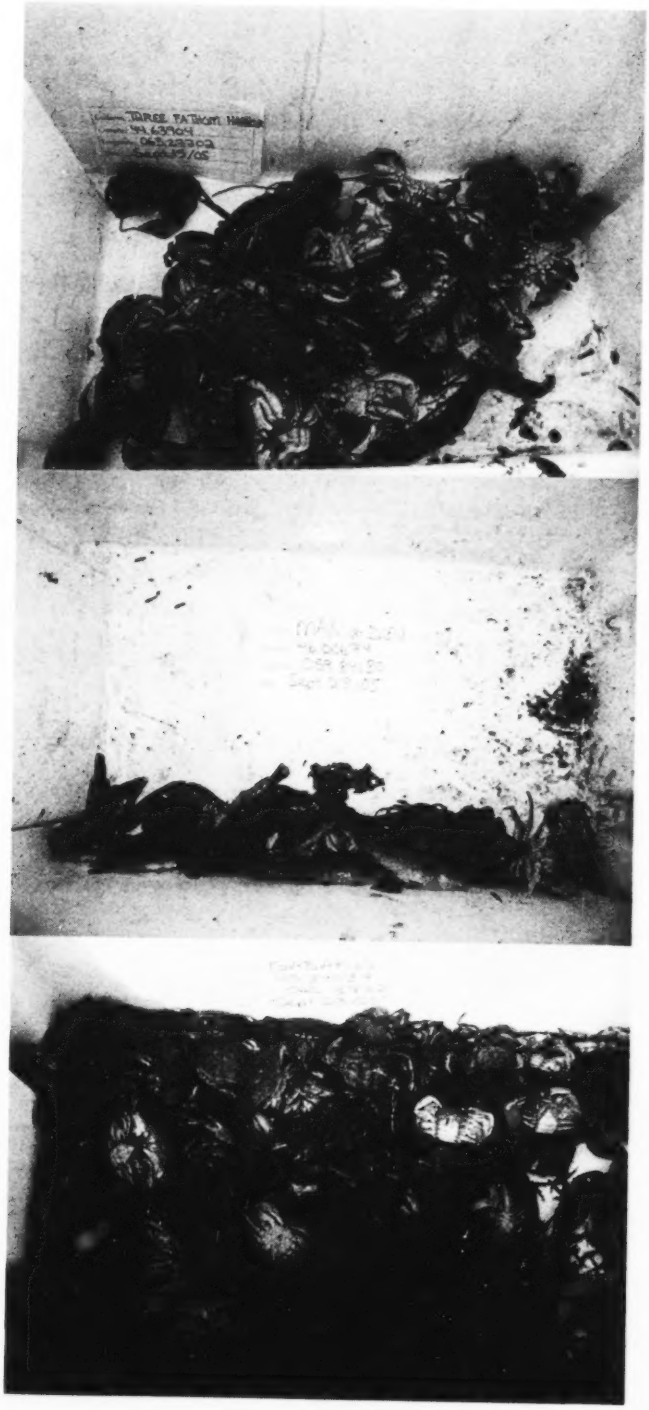


Fig.6. The catch from three traps in Three Fathom Harbour (Halifax county) (upper image), Main a Dieu (Cape Breton county) (middle image), and Gabarus (Cape Breton County) (lower image).

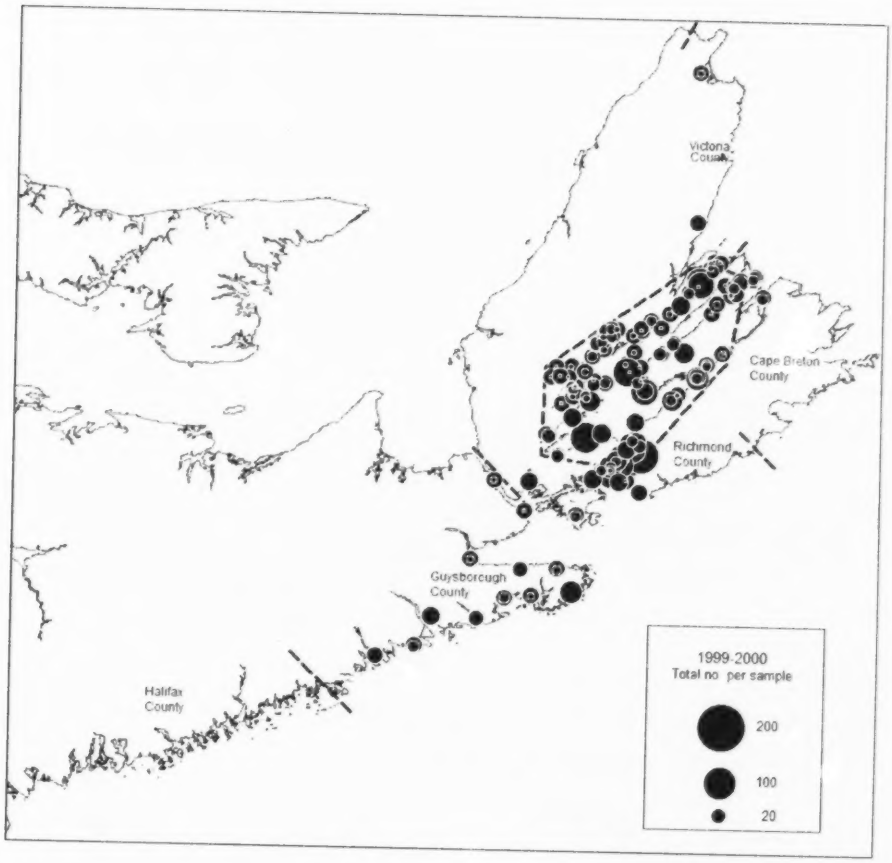


Fig. 7. Total number of green crab per sample (3 traps hauls) at sites visited in 1999-2000.

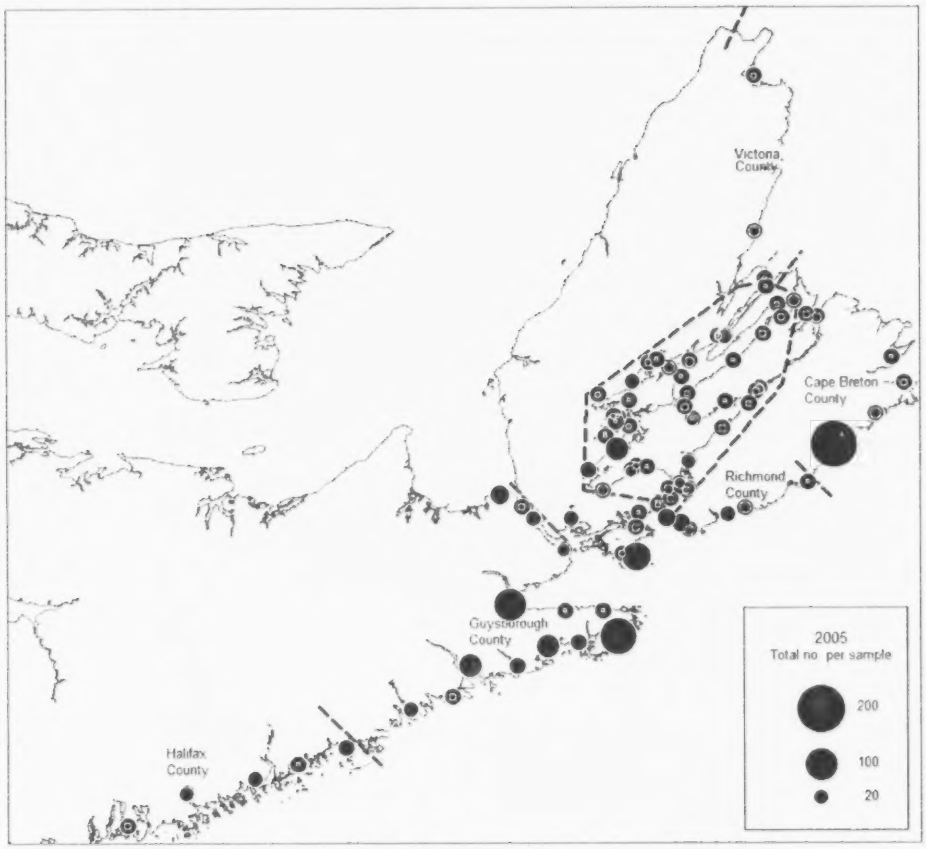


Fig. 8. Total number of green crab per sample (3 traps hauls) at sites visited in 2005.

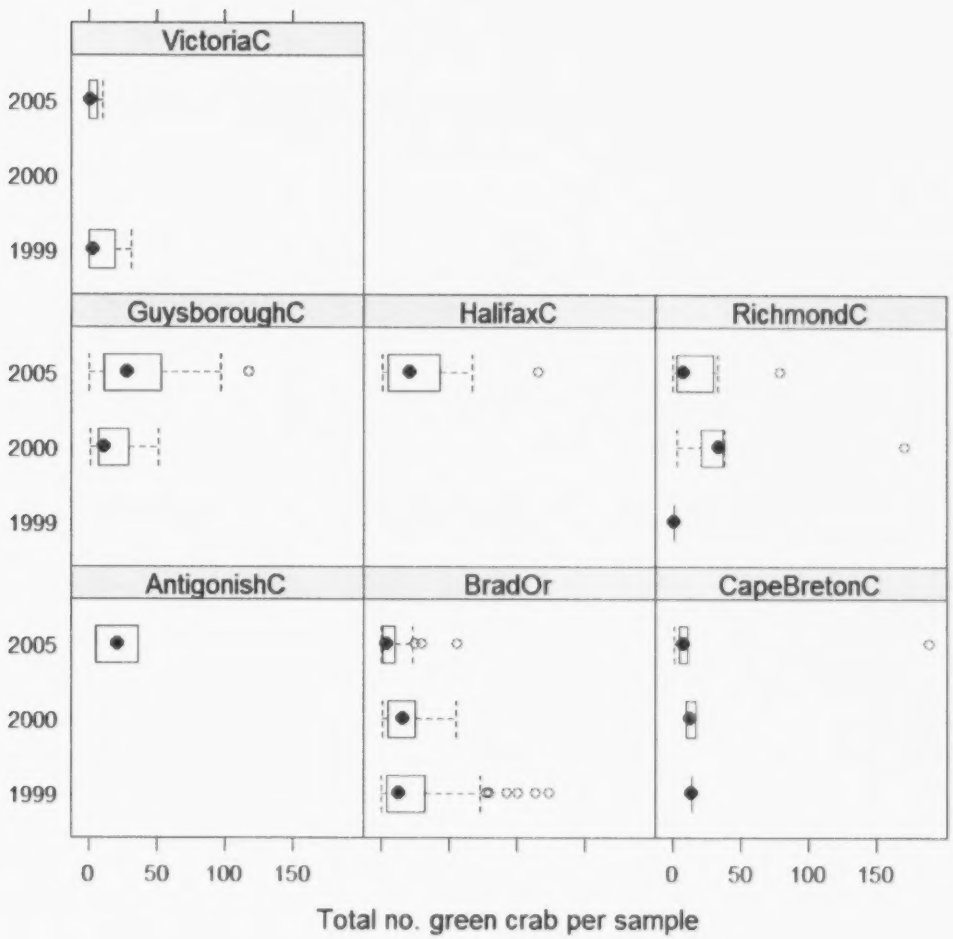


Fig. 9. Box plot of green crab catch rates (total number of per sample) for counties and for Bras d'Or Lakes by year.

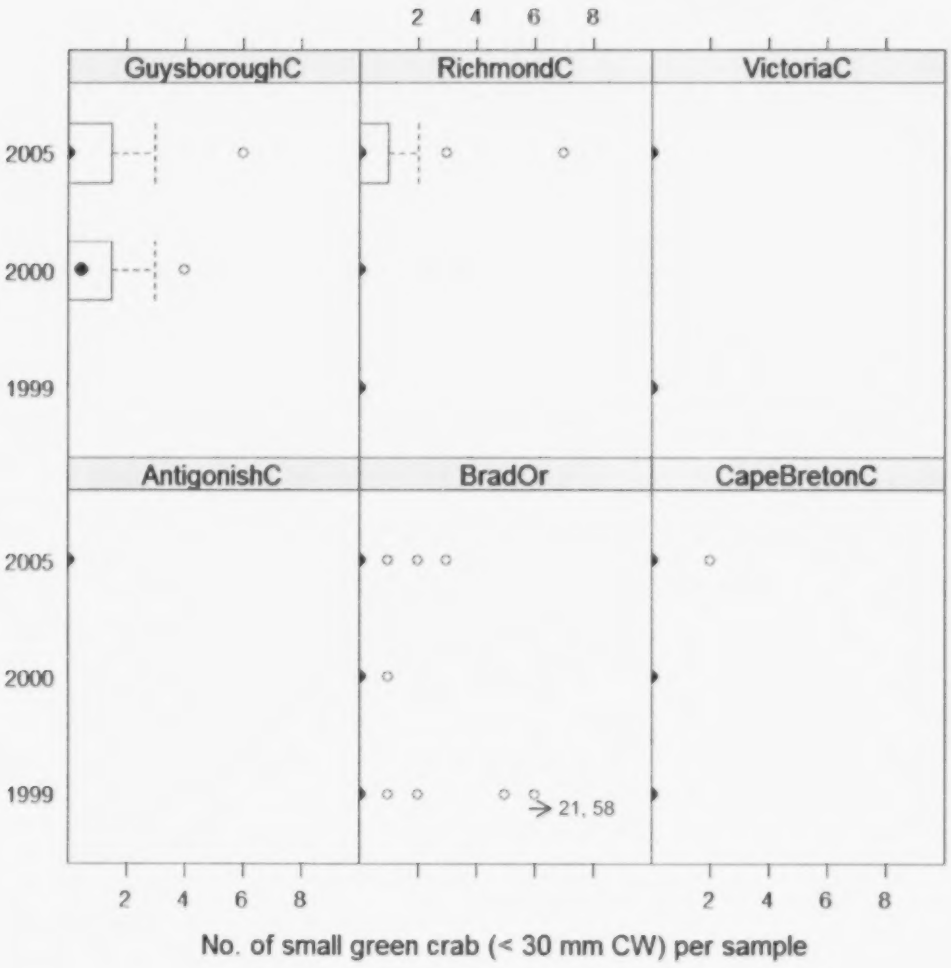


Fig. 10. Box plot of the catch rates of small green crab (< 30 mm CW) for counties and for Bras d'Or Lakes by year. Note the two off-scale observations for Bras d'Or Lakes in 1999. CW = Carapace width.

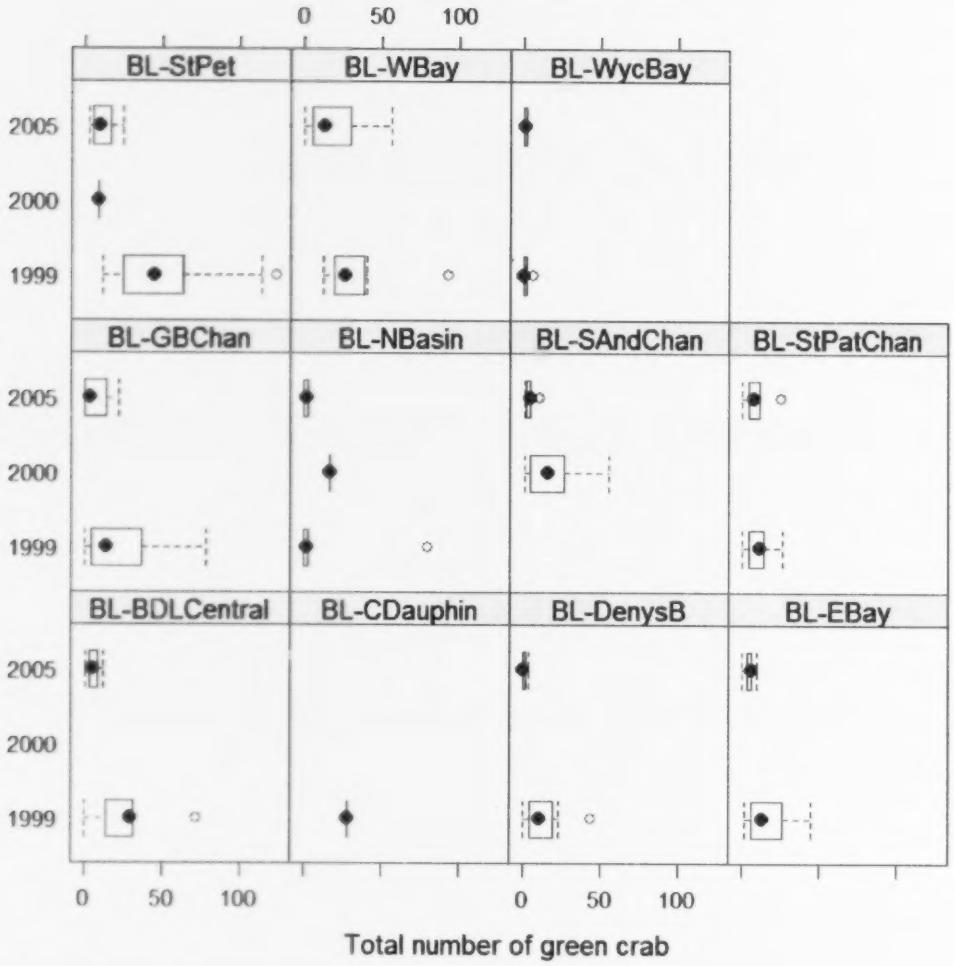


Fig. 11. Box plot of green crab catch rates (total number of per sample) for sites within Bras d'Or Lakes in different years. BL = Bras d'Or Lake; StPet = St. Peters, WBay = West Bay, WycBay = Whycocomagh Bay, GBChan = Great Bras d'Or Channel, NBasin = North Basin, SAndChan = St. Andrews Channel, StPatChan = St. Patrick's Channel, BDLCentral = Bras d'Or Lake central, CDauphin = Cape Dauphin, DenysB = Denys Basin, EBay = East Bay.

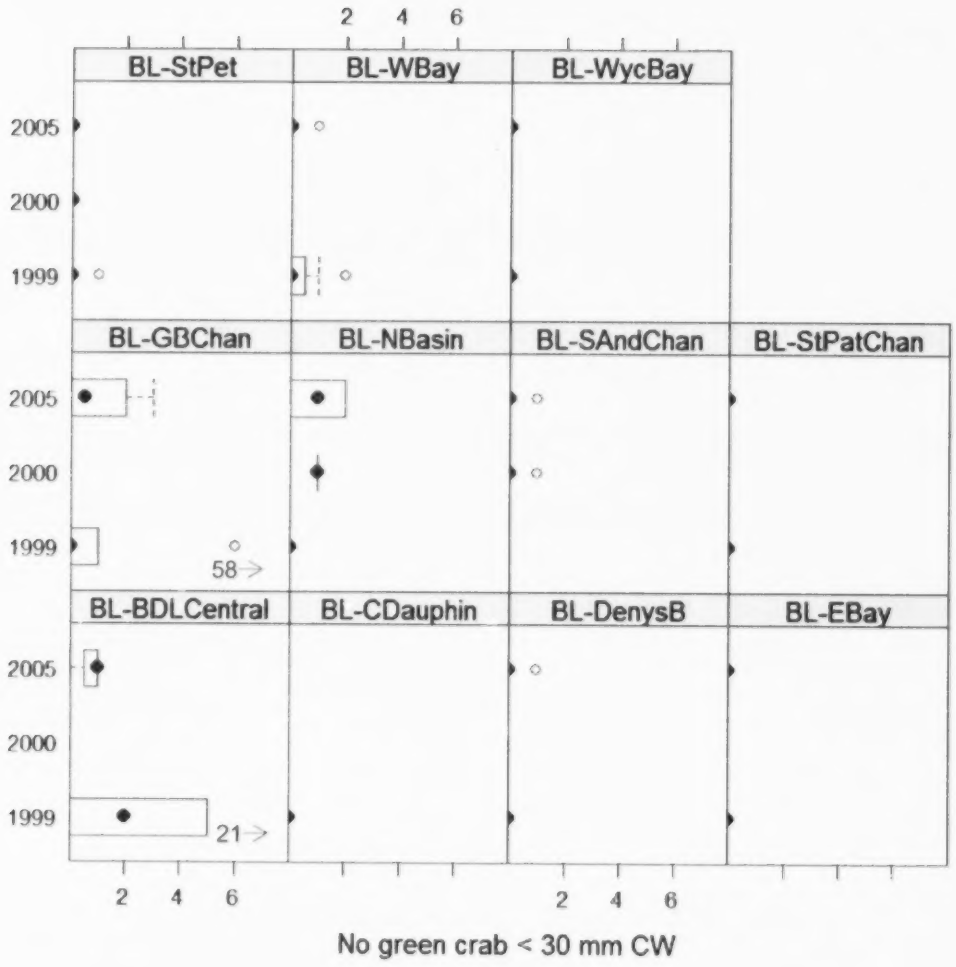
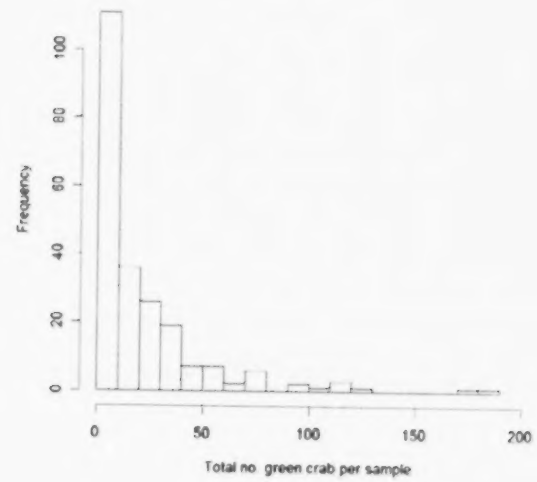


Fig. 12. Box plot of the catch rates of small green crab (< 30 mm CW) for subareas within Bras d'Or Lakes. Note the off-scale observations in 1999.



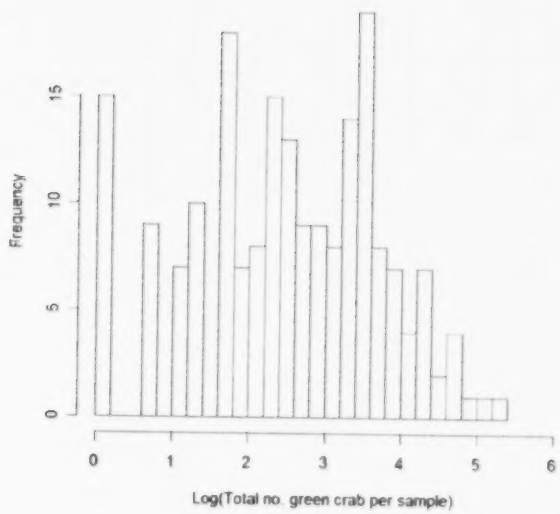


Fig. 13. Histogram of total counts of green crab per sample (= 3 trap hauls at a site on a particular date). (a) Raw data; number of samples with 0 crabs = 27,
(b) $\log_e$-transformed data (0 counts removed).

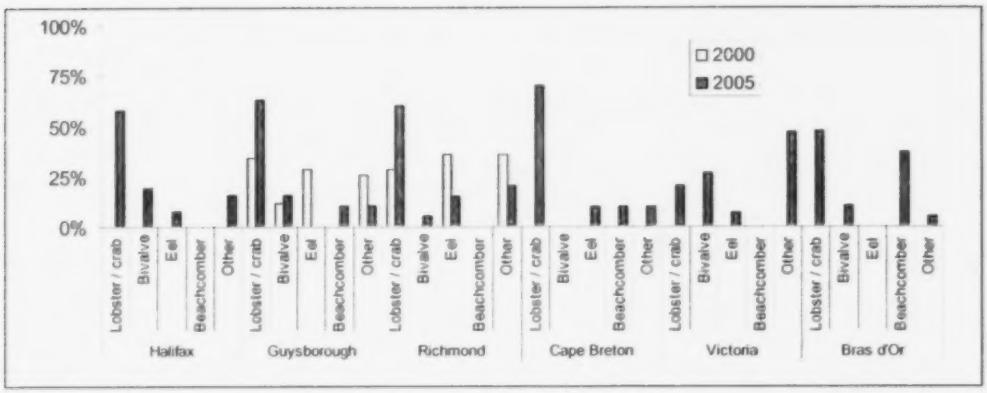


Fig. 14. Responses to interview question 1 by county and year: How do you observe coastal sea life?

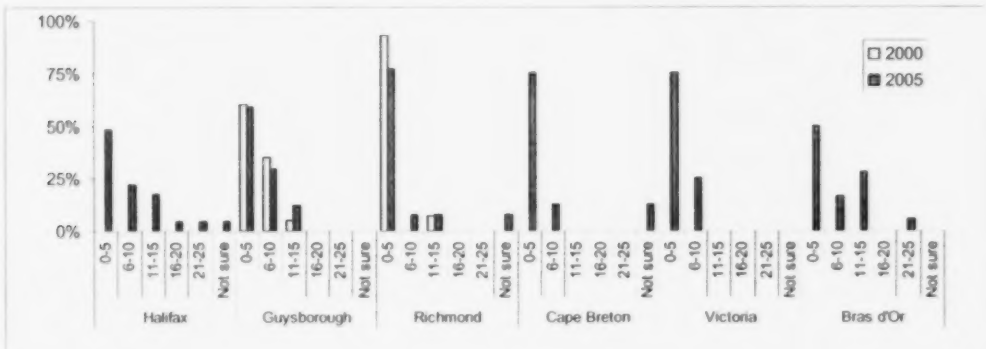


Fig. 15. Responses to interview question 4b by county and year: What is maximum depth (m) you've seen green crab?

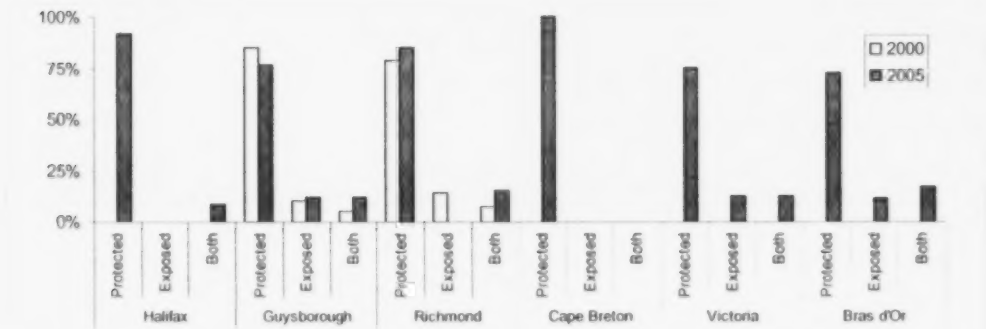


Fig. 16. Responses to interview question 4 by county: What was the habitat like where you first saw it (e.g. muddy, sandy, rocky, protected, exposed)?

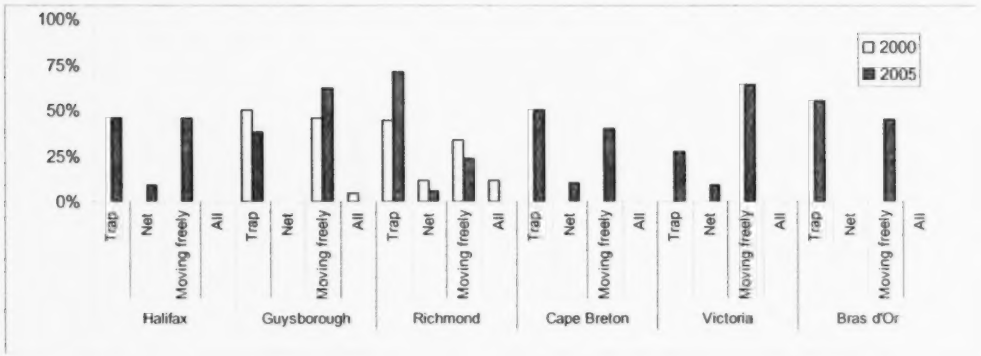


Fig. 17. Responses to interview question 6 by county: How did you see it…in a trap or moving freely along the shore?

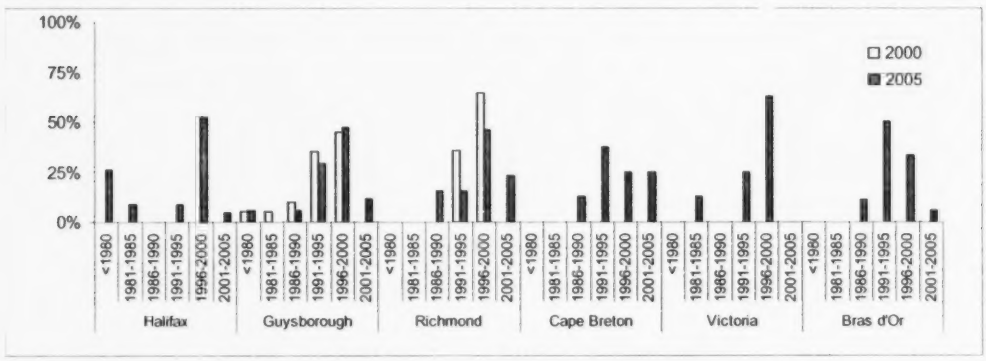


Fig. 18. Responses to interview question 7 by county: When was the first time you saw it?

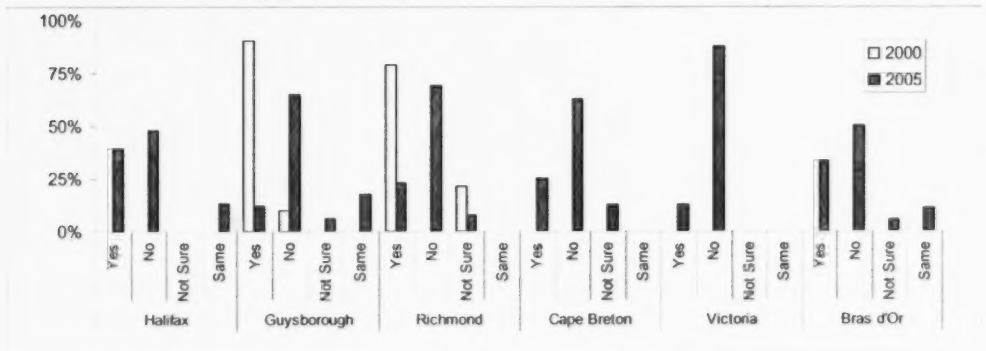


Fig. 19. Responses to interview question 9 by county: In your opinion are there more now then when you first saw it?

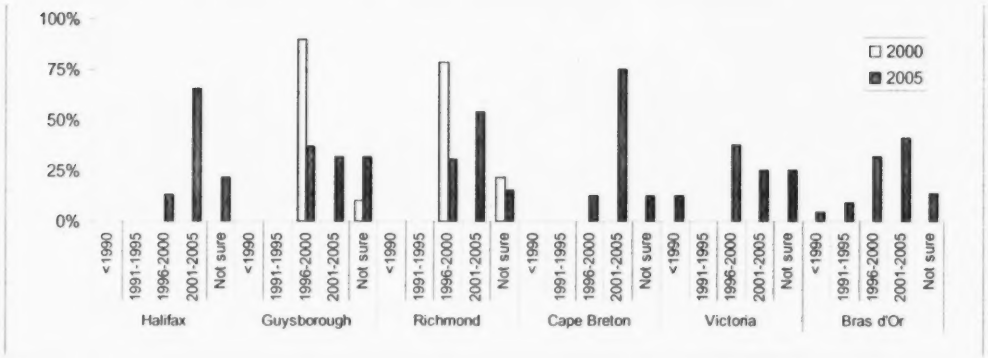


Fig. 20. Responses to interview question 10 by county: When do you recall them being the most numerous?

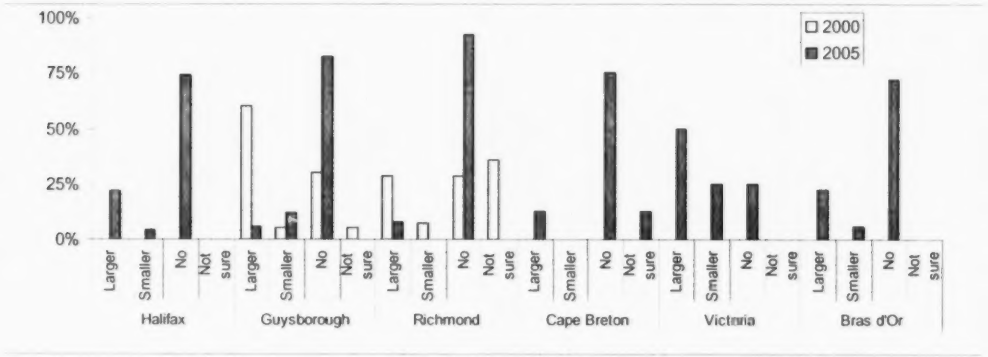


Fig. 21. Responses to interview question 12 by county: Any differences in the sizes you've seen recently (last 2 years) versus when you first saw it

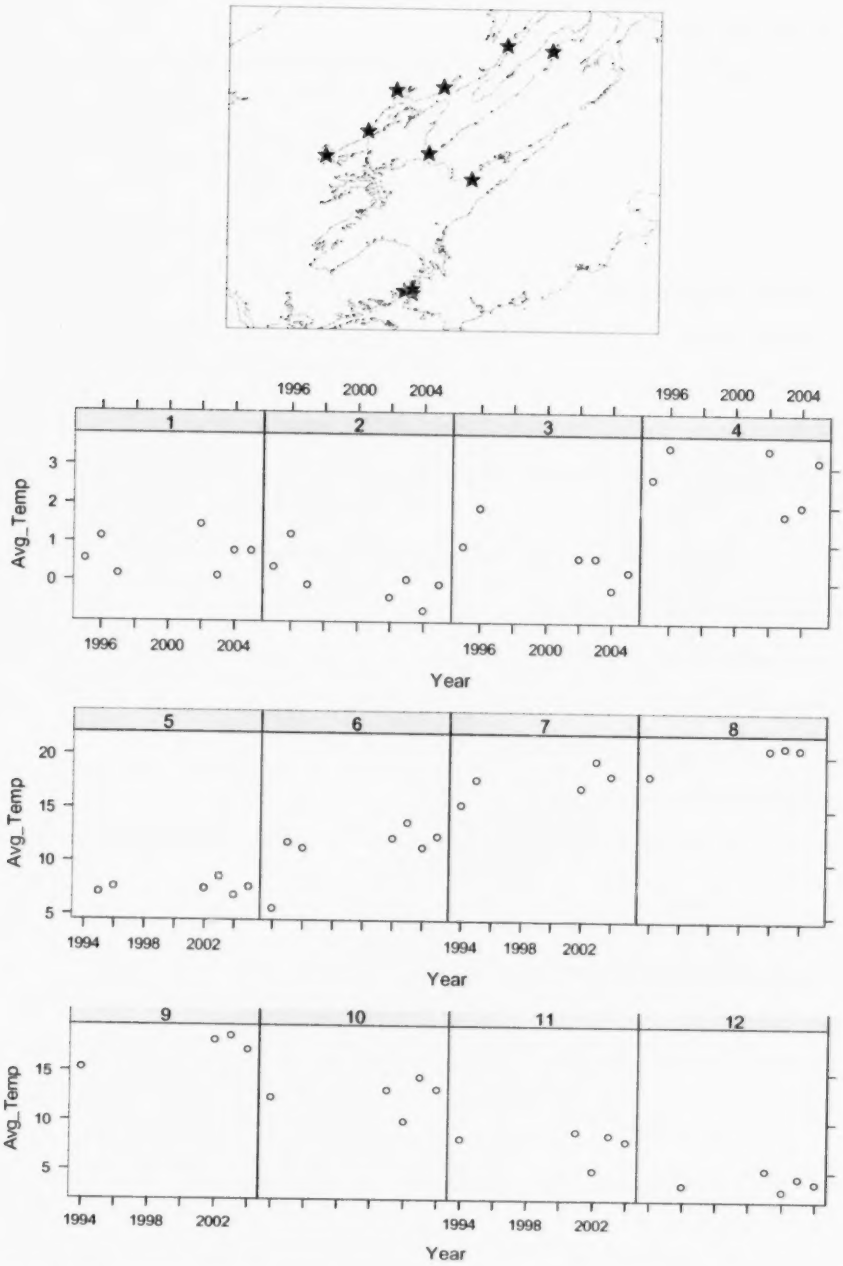


Fig. 22. Time series of mean temperatures (0-5 m depth) for each month in the Bras d'Or Lakes area from 1994-2005. Months are numbered consecutively (1=January). Map shows temperature recorder stations. Note that for any given station, data availability varied by season and year.

Appendix 1. Interview questions.

Name: Location:

Date:

---

1. How do you observe coastal sea life?
2. Have you ever seen a green crab (provide photos)
3. Where along the coast did you first see it?
4. What was the approximate depth (intertidal? Subtidal?). Maximum depth?
5. What was the habitat like where you first saw it (e.g. muddy, sandy, rocky, protected, exposed)?
6. How did you see it…in a trap or moving freely along the shore?
7. When was the first time you saw it?
8. Have you seen it continuously since then?
9. In your opinion are there more now then when you first saw it?
10. When do you recall them being the most numerous?
11. What sizes of crabs have you seen?
12. Any difference in the sizes you've seen recently (last 2 years) versus when you first saw it?
13. Ever seen a female with eggs? If yes, what time of year?
14. Ever seen a molted green crab? If yes, what time of year?

Other Comments:

Appendix 2. Analyses of variance and residual plots.

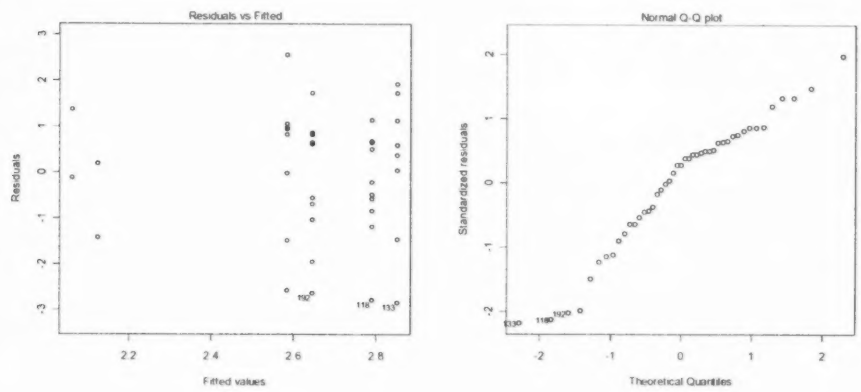
A. Analysis of data set for counties of Guysborough, Richmond and Victoria.

```
Analysis of Variance Table
Response: log(Totnoall)
              Df Sum Sq Mean Sq F value Pr(>F)
factor(Year2)  1  0.027   0.027  0.0149 0.9035
Region         2  1.905   0.952  0.5193 0.5988
Residuals     41 75.183   1.834

Model summary:
Residuals:
    Min      1Q  Median      3Q     Max
-2.8517 -0.8448  0.3671  0.8505  2.5567

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)              2.85174    0.35265   8.087 5.04e-10 ***
factor(Year2)19992000 -0.06103    0.40493  -0.151    0.881
RegionRichmondC       -0.20576    0.42729  -0.482    0.633
RegionVictoriaC       -0.72732    0.73365  -0.991    0.327
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.354 on 41 degrees of freedom
Multiple R-Squared: 0.02505,    Adjusted R-squared: -0.04628
F-statistic: 0.3512 on 3 and 41 DF,  p-value: 0.7885
```



Appendix Fig. 1. Residual plots from model Log(total count) ~ Year + Region. Regions are three counties: Guysborough, Richmond and Victoria. Left panel is residuals vs fitted values; right panel is a normal probability plot of the standardized residuals.

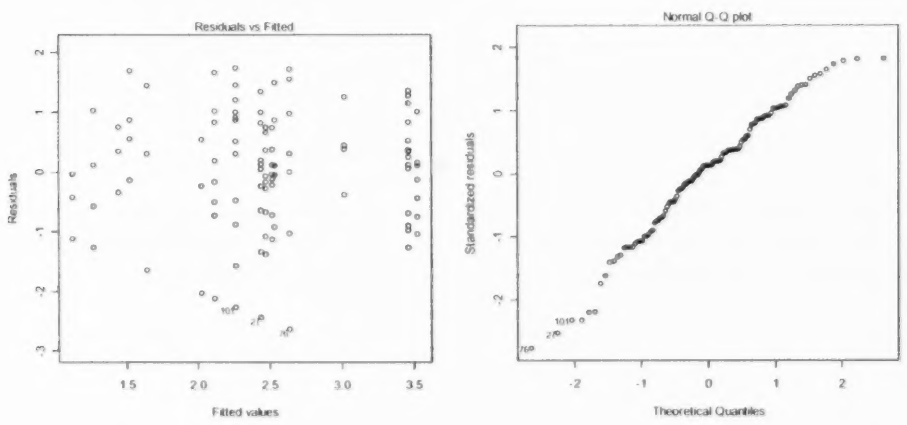
Appendix 2. Continued. B. Analysis of Bras d'Or Lakes only data set.

```
Call:
lm(formula = log(Totnoall) ~ factor(Year2) + RegionCounty, data =
subset(gcrabcpue,
    (Totnoall > 0) & (Region == "BradOr") & (RegionCounty !=
        "BL-CDauphin") & (RegionCounty != "BL-NBasin") & (RegionCounty !=
        "BL-WycBay")))

Analysis of Variance Table
Response: log(Totnoall)
                Df  Sum Sq Mean Sq F value    Pr(>F)
factor(Year2)    1  18.165  18.165 18.1866 4.252e-05 ***
Subarea          7  33.167   4.738  4.7436 0.0001097 ***
Residuals      110 109.871   0.999

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
---------------
Model Summary
Residuals:
    Min      1Q  Median      3Q     Max
-2.6343 -0.6605  0.1185  0.7459  1.7461
Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                 2.0237     0.3949   5.124 1.29e-06 ***
factor(Year2)19992000       0.9934     0.2015   4.930 2.93e-06 ***
Subarea BL-DenysB          -0.9016     0.4598  -1.961   0.0524 .
Subarea BL-EBay            -0.5810     0.4635  -1.253   0.2127
Subarea BL-GBChan          -0.3828     0.4842  -0.791   0.4309
Subarea BL-SAndChan        -0.7558     0.4462  -1.694   0.0931 .
Subarea BL-StPatChan       -0.5003     0.4543  -1.101   0.2732
Subarea BL-StPet            0.4447     0.4276   1.040   0.3006
Subarea BL-WBay             0.5081     0.4686   1.084   0.2807
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9994 on 110 degrees of freedom
Multiple R-Squared: 0.3184,     Adjusted R-squared: 0.2689
F-statistic: 6.424 on 8 and 110 DF,  p-value: 7.8e-07
```



Appendix Fig. 2. Residual plots from model Log(total count) ~ Year + subarea for Bras d'Or Lakes data. Left panel is residuals vs fitted values; right panel is a normal probability plot of the standardized residuals.